

# Three-dimensional Acetabular Bone Defect Classification System Aided with Rapid Prototyping Model and Reliability and Validity Test

**Jingwei Zhang**

Shanghai 9th Peoples Hospital Affiliated to Shanghai Jiaotong University School of Medicine

**Yi Hu**

Shanghai 9th Peoples Hospital Affiliated to Shanghai Jiaotong University School of Medicine

**Hua Ying**

Shanghai Jiao Tong University School of Medicine Affiliated Ninth People's Hospital

**Yuanqing Mao**

Shanghai 9th Peoples Hospital Affiliated to Shanghai Jiaotong University School of Medicine

**Zhenan Zhu**

Shanghai 9th Peoples Hospital Affiliated to Shanghai Jiaotong University School of Medicine Library

**Huiwu Li** (✉ [huiwu1223@163.com](mailto:huiwu1223@163.com))

Shanghai Key Laboratory of Orthopaedic Implants <https://orcid.org/0000-0002-2084-2737>

---

## Research Article

**Keywords:** 3-dimensional, classification, hip revision arthroplasty, acetabular bone defect, rapid prototyping

**Posted Date:** November 10th, 2021

**DOI:** <https://doi.org/10.21203/rs.3.rs-1050765/v1>

**License:** © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

---

# Abstract

**Background:** Accurately assessing acetabular defects and designing precise and feasible surgical plans are important before hip revision arthroplasty. With the development of three-dimensional printing, rapid prototyping is a novel technique used to print isometric physical object models. We aimed to propose a three-dimensional acetabular bone defect classification system aided with rapid prototyping and evaluated its reliability and validity.

**Methods:** We reviewed 104 consecutive patients who underwent hip revision arthroplasty in our department between January 2014 and December 2019. Forty five of them had rapid prototyping and were included for reliability and validity test. Three doctors retrospectively evaluated bone defects of these 45 patients with this classification and made surgical plans, and repeated it after 2 weeks. The intra- and inter-observer reliability and the validity to surgical records were assessed using intraclass correlation coefficient or Kappa correlation coefficient.

**Results:** The reliability and validity for classification results were high. The mean initial intraclass correlation coefficient for inter-observer reliability was 0.947, which increased to 0.972 when texted second time. As for inter-observer reliability, it ranged from 0.958 to 0.980. The validity showed high Kappa correlation coefficient of 0.951 to 0.967. When considering detailed surgical plans, the reliability and validity were also high with intraclass correlation coefficient and Kappa correlation coefficient all over 0.9.

**Conclusions:** This three-dimensional acetabulum defect classification was of high reliability and convincing validity. With this classification and objective rapid prototyping models, accurate bone defect assessment and reliable surgical plans were achieved. This classification aided with rapid prototyping could serve as a promising tool for surgeons for preoperative evaluation.

## Introduction

With the amount of hip revision arthroplasty increasing(1–3), acetabular bone defects have become a main challenge(4). Accurately assessing defects and designing precise and feasible surgical plans are critical for successful surgeries(5).

There have been several acetabular defect classifications, including classifications described by Paprosky(6), the American Academy of Orthopaedic Surgeons(AAOS)(7), Engh(8) and Gross(9). However, the classification by Paprosky, the AAOS or Gross was reported to have only poor to moderate reliability(10). The Engh classification was a simplified version of the AAOS classification, but it was still of low reliability or validity(11). Although the Paprosky classification was useful for clinical practice (12), information was limited(13). Besides, current classifications were more significant in evaluating simple acetabular defects than complex defects(14). Few classification systems can accurately guide surgical plans at present(11).

One reason for this is that most classifications used currently were proposed in the 1990s and limited by radiological techniques at that time. They were mainly depended on two-dimensional (2D) X-rays which only provided general anatomical clues(14–17) and did not represent three-dimensional (3D) structures accurately. With the development of 3D printing technology, rapid prototyping (RP) is used to convert standard 3D-computed tomography (CT) images into an isometric physical model in which physicians can accurately obtain key information which might be difficult to obtain through traditional images alone and can intuitively simulate various surgical plans and design implants(18). RP is proved to have more advantages in assessing bone defects and designing surgical plans in complex anatomical areas and revision cases compared to X-rays or CT scans(18–22).

Our joint reconstruction department has used RP for pre-operative evaluation and surgical planning for revision patients with acetabular defects. In this study, we proposed our 3D acetabulum defect classification system aided with RP and the corresponding surgical approaches, and tested the reliability and validity.

## Method

### Patients Enrolment and RP model building

This study was approved by the ethics committee of our hospital. We reviewed totally 104 consecutive patients who underwent hip revision arthroplasty in our department from January 2014 to December 2019 for aseptic acetabular prosthesis loosening or osteolysis. After admitted to hospital, anteroposterior and lateral radiographs (Siemens, RAX, Germany) of the affected hip were taken. If acetabulum defects were detected by X-rays, CT scans(Siemens, SOMATOM Definition Flash, Germany) were performed for more specific examination, covering the bilateral anterior iliac spine and the posterior borders of the medial and lateral condyles with 0.5-mm interspacing thickness. If severe defects which might hamper commercial prosthesis placing or affect initial stability were detected on CT and augments might be needed in operation(22, 23), RP was printed. 45 of these 104 patients were diagnosed as having severe defects and RP models for them were prepared before operation for further preoperative planning. The surgery was performed by the same group of experienced qualified surgeons. Intraoperative finding and surgical treatments adopted were taken as gold standard for comparison. Surgery were all successful and follow-up results were good to date. These 45 patients were included in this study for further reliability and validity test.

RP is a technique used to convert CT into an isometric physical object model using 3D printing(18). For patients who needed RP, CT scans were performed. The CT results were imported into Mimics (version 19.0, Materialise, Belgium) to rebuild CT model. RP was made by selective laser sintering using polylactic acid through 3D printing technology (RS4500 Stereolithography, Liantai, China) based on CT model. The resolution of the RP model is 0.1mm and it takes 24 hours for painting and costs approximately \$470 or \$780 for the hemi or whole pelvis, respectively.

# Classification system

Based on our experience of dealing such patients, we proposed our 3D acetabulum defect classification system as follows:

Type I, no obvious or only minor acetabular defects. The rotational and vertical primary stability of the cup can be provided by host bone.

Type II, there is effective bone mass in the antero-superior acetabulum, the ischial ramus and the pubic ramus, while defects exist in the stress-bearing posterosuperior acetabulum. The host bone only provides rotational stability for the cup.

Type III, defects in the anterosuperior acetabulum, the ischial ramus or the pubic ramus. Both rotational and vertical primary stabilities are lost.

Type IV, sever destruction of acetabular structures with high risk of pelvic discontinuity.

## Corresponding surgical plans

The surgical plans below are solutions which might be useful based on our experience, but not the only reconstruction method (Figure 1).

For Type I, an intact acetabular ring can be obtained by slight drilling. A commercial cup is used (Figure 2).

For Type II, the rotational stability of the cup can be provided by a three-point fixation distributed over 180 degrees (Figure 3). Depending on bone defects and the vertical stability, surgical plans are divided into three detailed situations:

1) With no obvious defects in the stress-bearing posterosuperior acetabulum, the rotational and vertical primary stability can be obtained. A commercial cup is used (Figure 4).

2) With cavity defects in the stress-bearing acetabulum, the vertical stability can be provided by postero-superiorly placed augments. Since commercial augments are enough to achieve effective fixation in cavity defects, it can be treated by a commercial cup with commercial augments (Figure 5).

3) With un-contained defects in the stress-bearing region, the posterosuperior acetabulum is damaged into a plain wall. The shearing force will be quite large only using commercial augments. Therefore, customised augments with fixed hooks or a buttress plate is necessary to avoid large shearing force (Figure 6).

Type III, when the anterosuperior acetabulum or the ischial ramus is defected, a buttress plate or a customised augment is used to repair it. After that, cup is fixed by an over 180 degrees three-point fixation

together with the pubic ramus. A cup-cage or a customised cage can also be used as an alternative (Figure 7). When more than two of these three structures are defected, a three-point fixation is lost. Hence, a cup-cage or customised Cage is required (Figure 8).

Type IV, a customised hemi-pelvic prosthesis is required (Figure 9).

## Reliability and validity test and data analysis

Three experienced surgeons qualified for joint revision were asked to use the above classification to evaluate bone defects and make surgical plans independently and retrospectively for all enrolled 45 patients. The surgeon had access to X-ray, CT and RP. The detailed information related to the patient was concealed, except for an identifying number. The classification results and corresponding surgical plans were recorded. This process was repeated after 2 weeks with the patient sequence to be evaluated disrupted. Classification results and corresponding surgical plans were assessed for reliability within and between these surgeons and for validity compared to previous surgical records. Statistical analyses were performed by SPSS (version 26.0, IBM, USA). Intraclass correlation coefficient (ICC) was used to reflect the inter and intraobserver reliability and Kappa ( $\kappa$ ) correlation coefficient was to reflect the validity. The mean value and 0.95 confidence interval were given.

## Results

According to this classification, 30 of these patients were classified as Type II, 9 patients as Type III and 6 patients as Type IV by referring to surgical records.

The ICC and  $\kappa$  values for the reliability and validity test for the classification results were high (Table 1&2). The mean initial inter-observer ICC was 0.947, which increased to 0.972 when tested second time. Regarding intra-observer ICC, the values for three surgeons ranged from 0.958 to 0.980. The mean  $\kappa$  value for validity to surgical records was 0.951 to 0.967. When considering detailed surgical plans, high ICC and  $\kappa$  values were maintained (Table 1&3). The mean initial inter-observer ICC was 0.960 and increased to 0.968 when tested again. The intra-observer ICC values for three surgeons were 0.988, 0.963 and 0.987, respectively. The mean  $\kappa$  value for validity was also high, reaching over 0.922.

This indicated that the classification results and surgical plans were of good intra- and inter-observer reliability and high validity compared to previous surgical records.

Table 1. The ICC values of inter-observer reliability

	Classification results	Surgical plans
1 <sup>st</sup> Test	0.947 (0.915-0.969)	0.960 (0.936-0.976)
2 <sup>nd</sup> Test	0.972 (0.955-0.984)	0.968 (0.948-0.981)

Table 2. The ICC values of intra-observer reliability for the classification results and the mean  $\kappa$  values for validity

	The ICC values	The $\kappa$ values
Surgeon 1	0.980 (0.964-0.989)	0.952
Surgeon 2	0.958 (0.925-0.977)	0.967
Surgeon 3	0.980 (0.964-0.989)	0.951

Table 3. The ICC values of intra-observer reliability for the surgical plans and the mean  $\kappa$  values for validity

	The ICC values	The $\kappa$ values
Surgeon 1	0.988 (0.978-0.993)	0.943
Surgeon 2	0.964 (0.935-0.980)	0.922
Surgeon 3	0.987 (0.976-0.993)	0.929

## Discussion

Accurately assessing acetabular defects and making surgical plans accordingly are critical to ensure successful surgeries(5). However, current acetabular defect classifications have kinds of disadvantages(8, 10, 11, 24–28). Campbell(10) assessed the reliability of three major acetabular classifications described by Paprosky(6), the AAOS(7) and Gross(9). The innovator group reached only moderate range of intraobserver agreement and for the non-innovator group, the intraobserver and interobserver agreement was even worse for all 3 classifications assessed. Gozzard(25) reported Paprosky classification system achieved moderate to good levels of agreement and bone stock loss classification systems were inconsistent and unreliable, which prevented realistic comparison of results within or between centers. Johanson(11) reviewed six acetabular defect classification systems and concluded that only one of them demonstrated required reliability and validity for a standardised grading system. Most current classifications only roughly guide surgical plans which need to be decided by specific perioperative situation.(6, 11, 13, 14) Campbell(10) claimed that the Paprosky system should be “considered only as a general guide” for its poor reliability. As a result, the degree of bone defects found during surgery may exceed surgeons’ expectations. However, adjusting surgical plan intra-operatively is difficult and insufficient preparation may lead to surgical failure and worse post-operative outcomes. In addition, current classifications have greater significance in evaluating relatively simple defects than complex cases(14). Ghanem(13) reported 16.37% of cases had further defects found intraoperatively than the preoperative plan and he suggested a practical, reproducible and valid classification system for preoperative planning.

One reason for this is that previous classifications were mostly based on traditional radiological techniques. It is difficult to realize 3D structures of bone defects through X- rays or CT model on 2D

computer screens and information is always incomplete(15–17). With 3D printing technology(18–22), 3D reconstructed RP displays 3D anatomy structure more intuitively and provides key information difficult to obtain from 2D images. Thus, RP aids surgeons to understand bone defects more intuitively and formulate surgical plans more comprehensively, which reduces errors and improves postoperative outcomes compared to x-rays or CT model(22).

For this reason, we proposed our 3D acetabulum defect classification system aided with RP. Since Type I in this classification was little defected and it was easy to distinguish from X-rays or CT, it was unnecessary to print RP models for such patients or take Type I cases into reliability and validity test.

This study showed both classification results and surgical plans were of good inter and intraobserver reliability and high validity compared to surgical records. It suggested our 3D classification helped classifying acetabular defects preoperatively and guiding reliable surgical plans. There might be several reasons for this. First, comprehensive information was accessible. In relative complex cases, RP presented bone defects and the rest bone mass through visible 3D models. Hence, demand on radiograph reading was less and no information was lost for evaluation. It became easier for surgeons to realise the real 3D structure of defected acetabulum. As a result, three surgeons made classifications and surgical plans of high intraobserver reliability. Second, anatomy structures displayed by RP was so intuitive that a surgeon gave a closing classification at the second time after the first impression, which explained high interobserver reliability. Third, evaluations were based on objective RP model, which could be utilised for surgery simulation to test plans' feasibility and reflect intraoperative situations preoperatively. Thus, classification results and surgical plans were of high validity. It was consistent with previous reports. Preoperative planning with RP before hip revision improved clinical results(18–22). Involving RP improved diagnosis accuracy in discovering fractures in complex anatomical areas, such as obscure pelvis fracture(29, 30).

In this classification, the leading factor to be considered is how to obtain the primary stability of a cementless cup, including rotational and vertical stability. Primary stability can be obtained either by effective three-point fixation distributed over 180 degrees or by enough screws fitting into wall.

We chose the anterosuperior acetabulum, the ischial ramus and the pubic ramus for a three-point fixation because other structures around the acetabulum are relatively thin and often destroyed in severely defected cases. Despite some bone mass remains, this kind of bone is of high density due to osteosclerosis. It is brittle and unable to provide effective holding. The three areas mentioned above have larger interface and thicker bone stock. The remaining bone will still be sufficient for holding even if osteolysis occurs around. Although the ischial ramus and anterosuperior acetabulum have a relatively large bone stock and some surgeons even believe the cup can be held with only these two points, it should be avoided as much as possible to our opinion. This is exactly the difference between type III and type II. In some type III cases, defects in the anterosuperior acetabulum or the ischial ramus can still be reconstructed with a buttress plate or augments and a three-point fixation can be obtained combining

other two places. If more than one place needs reconstruction, the above method might not provide sufficient holding and stable three-point fixation is important(13).

We classified cases with internal acetabular wall defected but an intact acetabular ring (Paprosky type 2C) into type II because when the remaining bone is enough to provide a three-point fixation, it is still feasible to hold the cup with augments or screws.

If type II has defects in the stress-bearing posterosuperior acetabulum, we believe the direct supporting between bone and prosthesis is the basic principle for achieving reliable long-term stability through bone remodelling. When structural or compression bone grafting is used, the progress of bone remodelling is so long that weight-bearing on the interface between the prosthesis and graft is inevitable. As a result, the prosthesis gets loosening quickly owing to micromotion. Our cases found that when there was no direct contact between the prosthesis and host bone but through allografts, although most allografts were well reconstructed, fatigue fracture occurred in the connection part to the cage due to micromotion (Figure 10). It is possible that the remoulding progress was so long that the grafted bone could not provide sufficient support to the prosthesis in the weight-bearing area although the grafted bone was well remodelled finally.

With cavity or uncontained defects in the weightbearing posterosuperior acetabulum as type II, augments are needed. When bone defects are not severe and the host bone thickness is still sufficient, conventional commercial augments can repair the defects and cup can be fixed by remaining acetabulum wall or screws. When uncontained defects or severe defects exist, stable fixation cannot be achieved. Despite some bone mass in adjacent ilium in some cases, it is difficult to directly fix an augment on to it. Customed augment fixed wings or a buttress plate is required.

We noticed few patients with defects only in the anterosuperior acetabulum in clinical practice. It is possibly because rare force passes the anterosuperior. Anterosuperior defects always occur together with posterosuperior defects, which result in defects in the superior acetabulum (type III). When severe osteolysis only occurs in either the superior acetabulum or the ischial ramus, a buttress plate or a customed augment with a wing can be used to reconstruct defected places to hold the cup. When more than two of these places are defected, the primary vertical and rotational stabilities cannot be obtained using conventional methods. Cup-cage or customised prostheses is recommended. At present, most commercial Cup-Cage is used when there are no serious bone defects at the bottom acetabulum. Cup-Cage can be fixed by an obturator hock into the obturator foramen or a hook bound to the upper edge of the obturator. Customised cages can be used for defects in many areas when rotational stability is difficult to obtain.

There are some disadvantages in this study. First, the original size of each patient's pelvis and remaining bone is different and it is difficult to classify quantitatively. However, only with this qualitative 3D classification, professional surgeons qualified for joint revision can already distinguish the extent of bone defect and design feasible surgical plans, which already accomplishes the goal of surgical planning. Second, the accuracy of showing effective bone mass by RP needs further improvements(18). However,

current accuracy already meets the needs for most clinical applications. Our recommended surgical strategies were feasible, but not the only method. Other experienced surgeons might have their own understandings and corresponding reconstruction methods.

## **Conclusion**

This 3D acetabulum defect classification is of high reliability and convincing validity. With this classification and objective RP model, surgeons evaluate bone defects intuitively and make more accurate surgical plans. This classification aided with RP model could serve as a promising tool for surgeons for preoperative evaluation.

## **Declarations**

### **Ethics approval and consent to participate**

This study was approved by the ethics committee of Ninth People's Hospital of Shanghai Jiao Tong University School of Medicine and all the participants had written informed consent.

### **Consent for publication**

All authors have seen the manuscript and approved it to submit to your journal.

### **Availability of data and materials**

The datasets used or analysed during the current study are available from the corresponding author on reasonable request.

### **Competing interests**

The authors declare no competing interests.

### **Funding**

This study was sponsored by National Nature Science Foundation of China (Grant No. 31900941) and the Interdisciplinary Program of Shanghai Jiao Tong University (project No. ZH2018QNA06).

### **Author contribution**

All authors contributed to the study conception and design. Data extraction and assessment were performed by JWZ, YH, HY. Research coordination was done by YQM, ZAZ, HWL. The first draft of the manuscript was written by JWZ, YH. All authors approved the final version of the manuscript.

## Acknowledgments

Not applicable

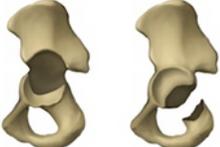
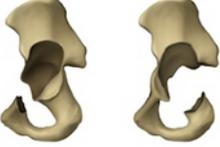
## References

1. Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. *J Bone Joint Surg Am.* 2007;89(4):780–5.
2. Patel A, Pavlou G, Mújica-Mota RE, Toms AD. The epidemiology of revision total knee and hip arthroplasty in England and Wales: a comparative analysis with projections for the United States. A study using the National Joint Registry dataset. *Bone Joint J.* 2015;97-b(8):1076–81.
3. Schwartz AM, Farley KX, Guild GN, Bradbury TL, Jr. Projections and Epidemiology of Revision Hip and Knee Arthroplasty in the United States to 2030. *J Arthroplasty.* 2020;35(6s):S79-s85.
4. Sheth NP, Nelson CL, Springer BD, Fehring TK, Paprosky WG. Acetabular bone loss in revision total hip arthroplasty: evaluation and management. *J Am Acad Orthop Surg.* 2013;21(3):128–39.
5. Melnic CM, Paprosky WG, Sheth NP. Management of Acetabular Bone Loss in Revision Total Hip Arthroplasty. *Instr Course Lect.* 2018;67:207–14.
6. Paprosky WG, Perona PG, Lawrence JM. Acetabular defect classification and surgical reconstruction in revision arthroplasty. A 6-year follow-up evaluation. *J Arthroplasty.* 1994;9(1):33–44.
7. D'Antonio JA, Capello WN, Borden LS, Bargar WL, Bierbaum BF, Boettcher WG, et al. Classification and management of acetabular abnormalities in total hip arthroplasty. *Clin Orthop Relat Res.* 1989(243):126–37.
8. Engh CA, Glassman AH, Griffin WL, Mayer JG. Results of cementless revision for failed cemented total hip arthroplasty. *Clin Orthop Relat Res.* 1988(235):91–110.
9. Gross AE, Saleh KJ, Wong P. Acetabular revision using grafts and cages. *Am J Orthop (Belle Mead NJ).* 2002;31(4):213–5.
10. Campbell DG, Garbuz DS, Masri BA, Duncan CP. Reliability of acetabular bone defect classification systems in revision total hip arthroplasty. *J Arthroplasty.* 2001;16(1):83–6.
11. Johanson NA, Driftmier KR, Cerynik DL, Stehman CC. Grading acetabular defects: the need for a universal and valid system. *J Arthroplasty.* 2010;25(3):425–31.
12. Telleria JJ, Gee AO. Classifications in brief: Paprosky classification of acetabular bone loss. *Clin Orthop Relat Res.* 2013;471(11):3725–30.
13. Ghanem M, Zajonz D, Heyde CE, Roth A. Acetabular defect classification and management: Revision arthroplasty of the acetabular cup based on 3-point fixation. *Orthopade.* 2020;49(5):432–42.

14. Horas K, Arnholdt J, Steinert AF, Hoberg M, Rudert M, Holzapfel BM. Acetabular defect classification in times of 3D imaging and patient-specific treatment protocols. *Orthopade*. 2017;46(2):168–78.
15. Kitamura N, Pappedemos PC, Duffy PR, 3rd, Stepniewski AS, Hopper RH, Jr., Engh CA, Jr., et al. The value of anteroposterior pelvic radiographs for evaluating pelvic osteolysis. *Clin Orthop Relat Res*. 2006;453:239–45.
16. Jerosch J, Steinbeck J, Fuchs S, Kirchhoff C. [Radiologic evaluation of acetabular defects on acetabular loosening of hip alloarthroplasty]. *Unfallchirurg*. 1996;99(10):727–33.
17. Claus AM, Engh CA, Jr., Sychterz CJ, Xenos JS, Orishimo KF, Engh CA, Sr. Radiographic definition of pelvic osteolysis following total hip arthroplasty. *J Bone Joint Surg Am*. 2003;85(8):1519–26.
18. Li H, Wang L, Mao Y, Wang Y, Dai K, Zhu Z. Revision of complex acetabular defects using cages with the aid of rapid prototyping. *J Arthroplasty*. 2013;28(10):1770–5.
19. Won SH, Lee YK, Ha YC, Suh YS, Koo KH. Improving pre-operative planning for complex total hip replacement with a Rapid Prototype model enabling surgical simulation. *Bone Joint J*. 2013;95-b(11):1458–63.
20. Zerr J, Chatzinoff Y, Chopra R, Estrera K, Chhabra A. Three-dimensional printing for preoperative planning of total hip arthroplasty revision: case report. *Skeletal Radiol*. 2016;45(10):1431–5.
21. Li H, Qu X, Mao Y, Dai K, Zhu Z. Custom Acetabular Cages Offer Stable Fixation and Improved Hip Scores for Revision THA With Severe Bone Defects. *Clin Orthop Relat Res*. 2016;474(3):731–40.
22. Zhang JW, Liu XL, Zeng YM, Zhai ZJ, Mao YQ, Yu DG, et al. Comparison of 3D Printing Rapid Prototyping Technology with Traditional Radiographs in Evaluating Acetabular Defects in Revision Hip Arthroplasty: A Prospective and Consecutive Study. *Orthop Surg*. 2021.
23. Van Kleunen JP, Lee GC, Lementowski PW, Nelson CL, Garino JP. Acetabular revisions using trabecular metal cups and augments. *J Arthroplasty*. 2009;24(6 Suppl):64–8.
24. Gross AE, Allan DG, Catre M, Garbuz DS, Stockley I. Bone grafts in hip replacement surgery. The pelvic side. *Orthop Clin North Am*. 1993;24(4):679–95.
25. Gozzard C, Blom A, Taylor A, Smith E, Learmonth I. A comparison of the reliability and validity of bone stock loss classification systems used for revision hip surgery. *J Arthroplasty*. 2003;18(5):638–42.
26. Paprosky WG, Bradford MS, Younger TI. Classification of bone defects in failed prostheses. *Chir Organi Mov*. 1994;79(4):285–91.
27. Käfer W, Fraitzl CR, Kinkel S, Puhl W, Kessler S. [Analysis of validity and reliability of three radiographic classification systems for preoperative assessment of bone stock loss in revision total hip arthroplasty]. *Z Orthop Ihre Grenzgeb*. 2004;142(1):33–9.
28. Parry MC, Whitehouse MR, Mehendale SA, Smith LK, Webb JC, Spencer RF, et al. A comparison of the validity and reliability of established bone stock loss classification systems and the proposal of a novel classification system. *Hip Int*. 2010;20(1):50–5.

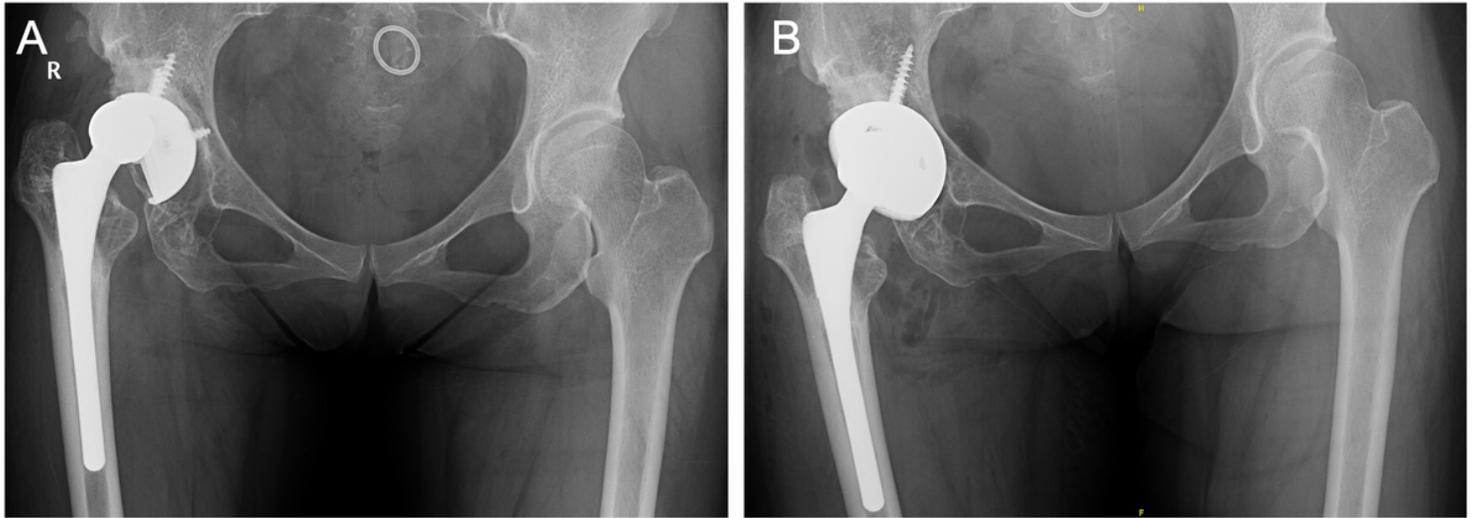
29. Zheng SN, Yao QQ, Mao FY, Zheng PF, Tian SC, Li JY, et al. Application of 3D printing rapid prototyping-assisted percutaneous fixation in the treatment of intertrochanteric fracture. *Exp Ther Med*. 2017;14(4):3644–50.
30. Hurson C, Tansey A, O'Donnchadha B, Nicholson P, Rice J, McElwain J. Rapid prototyping in the assessment, classification and preoperative planning of acetabular fractures. *Injury*. 2007;38(10):1158–62.

## Figures

Classification	Recommended reconstruction methods	
Type I		
Type II		
		
		
Type III		
		
Type IV		

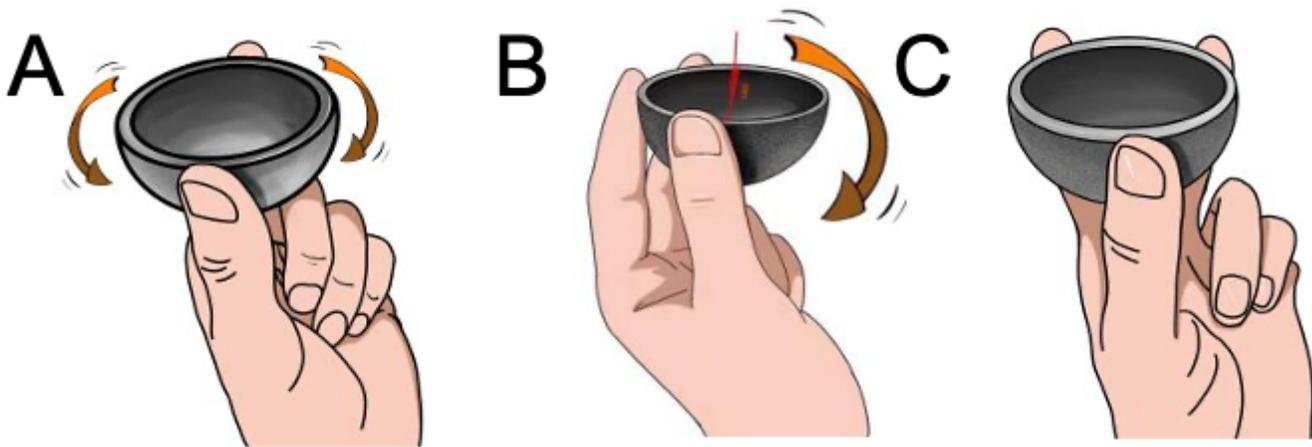
**Figure 1**

Illustration of the classification system and possible reconstruction methods.



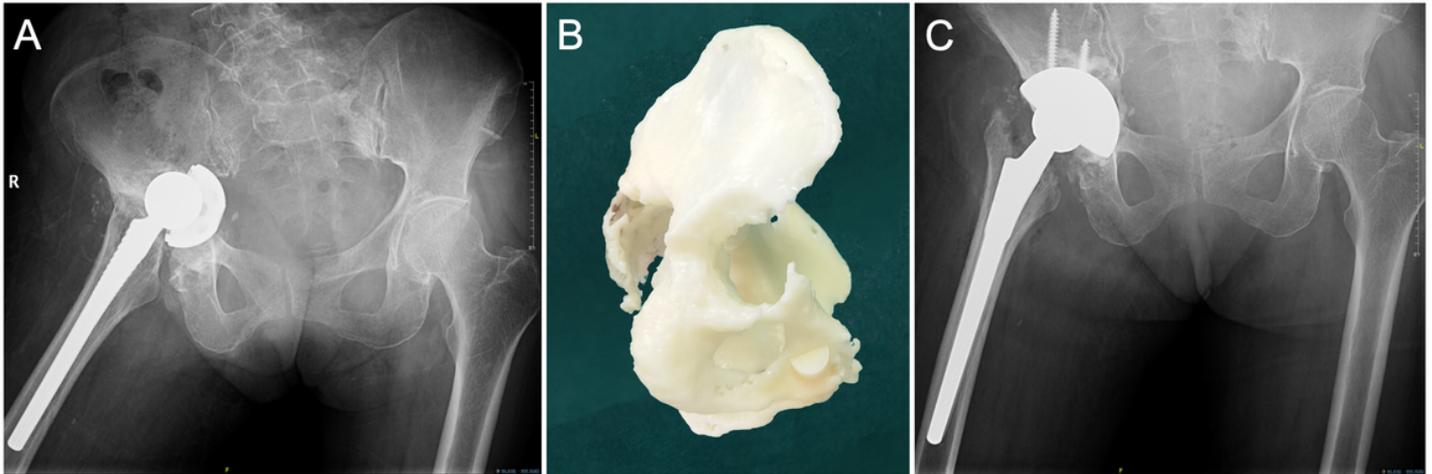
**Figure 2**

A. A 47-year-old female was diagnosed as aseptic loosening with small defects in acetabulum but an intact acetabular ring 13 years after THA. B. A commercial cup was used.



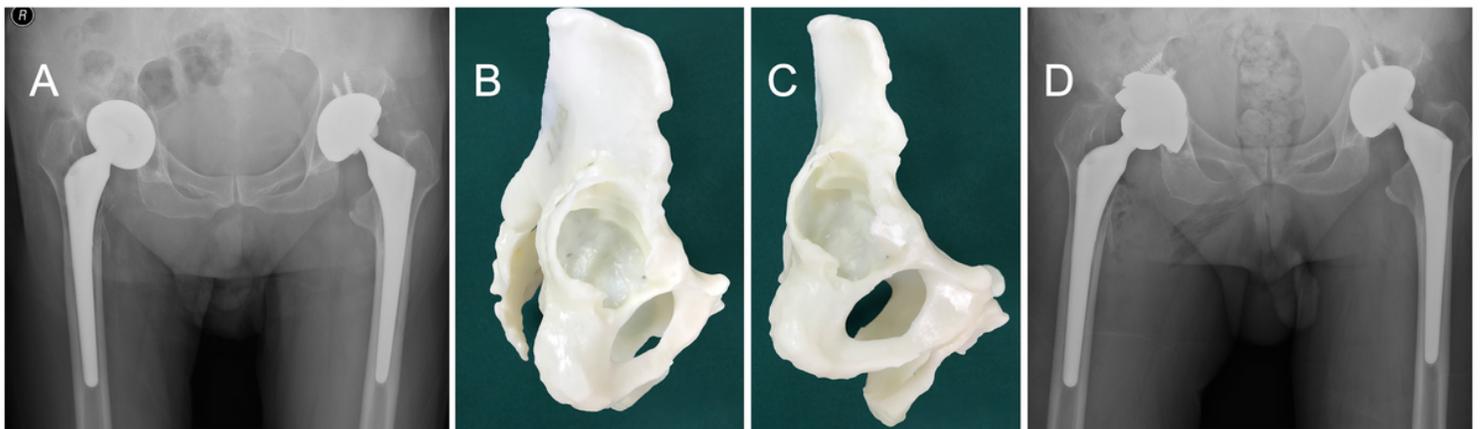
**Figure 3**

Illustration of the three-point fixation distributing over 180 degrees. A. the cup rotates when only fixed by two points; B. the cup inclines to the unsupported side when fixed by three points distributing within 180 degrees; C. three points distributing over 180 degrees hold the hemisphere cup firmly.



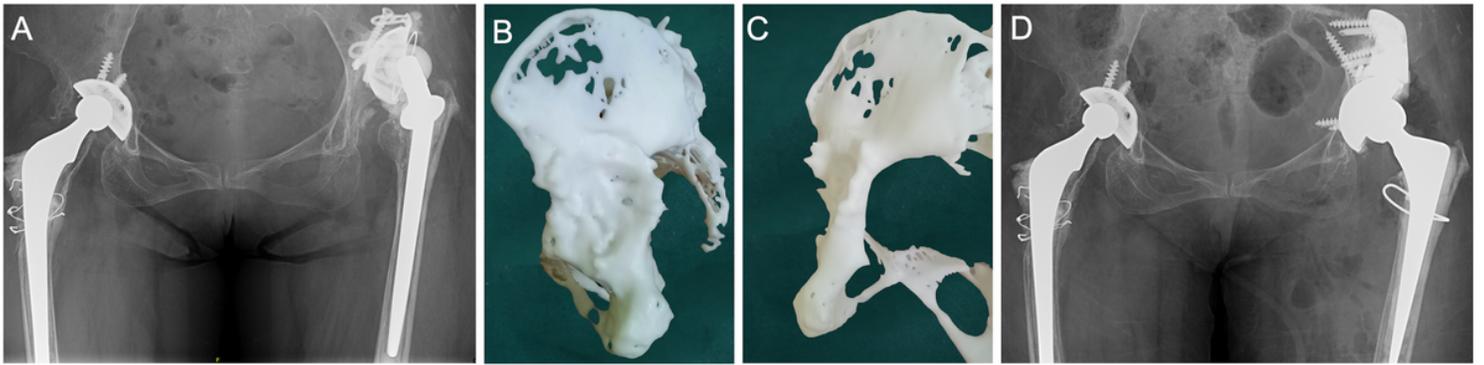
**Figure 4**

A. A 77-year-old female was diagnosed as aseptic loosening. B. RP showed defects in the anteroinferior acetabulum. The anterosuperior acetabulum, the ischial ramus, the pubic ramus and stress-bearing posterosuperior acetabulum were intact. C. Primary vertical and rotational stability was achieved with a commercial cup.



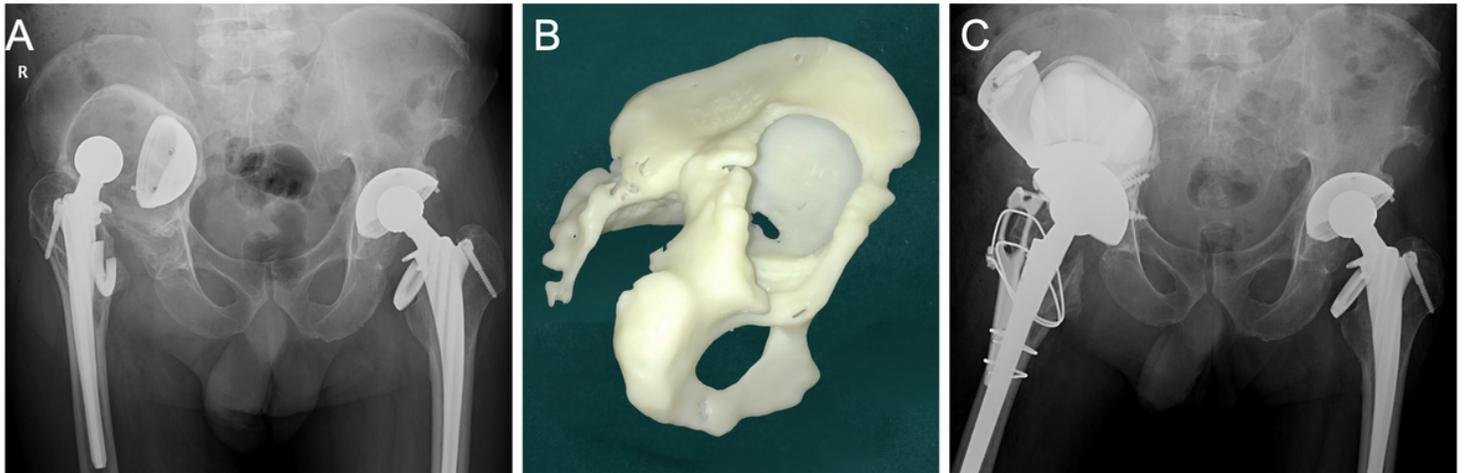
**Figure 5**

A. A 74-year-old male was diagnosed as aseptic loosening 4 years after THA. B-C. RP showed defects in the anteroinferior acetabulum and cavity defects in the posterosuperior. The vertical stability was relied on the reconstruction of the stress-bearing acetabular region by commercial augments. D. Commercial augments and a cup were used to reconstruct the acetabulum.



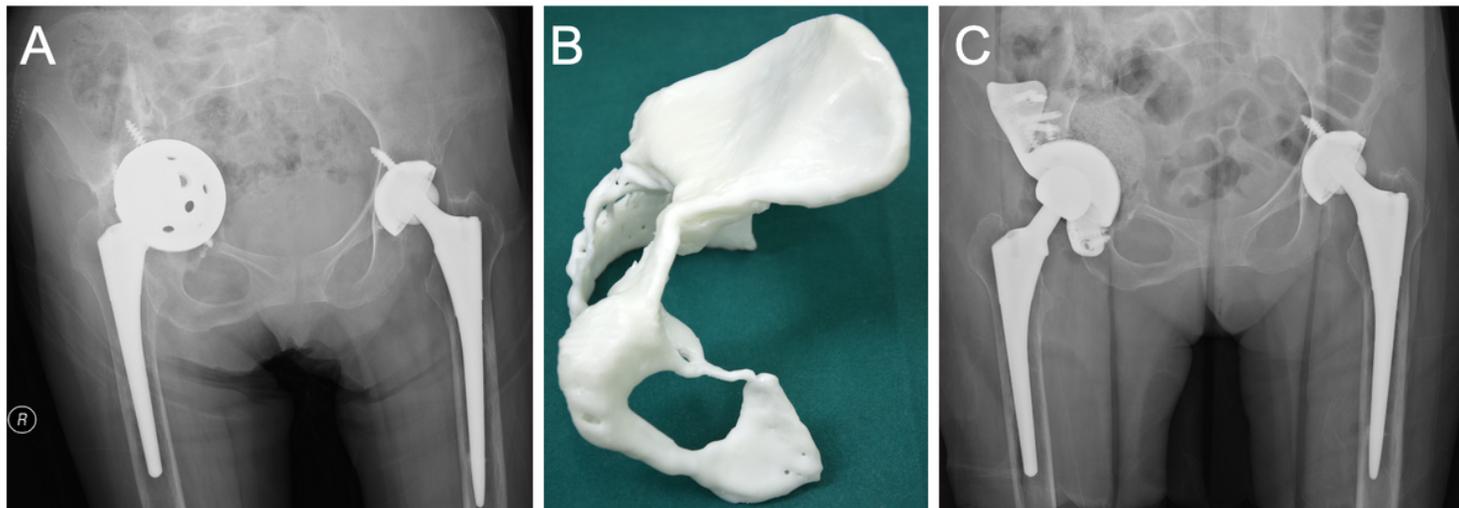
**Figure 6**

A. A 62-year-old female was diagnosed as aseptic loosening 20 years after THA. B-C. RP showed uncontained defects in the posterosuperior acetabulum. The vertical stability could be achieved by reconstructing the posterosuperior stress-bearing acetabulum with augments with wing. D. A customized augment with a wing was used to reconstruct the acetabulum with a commercial cup.



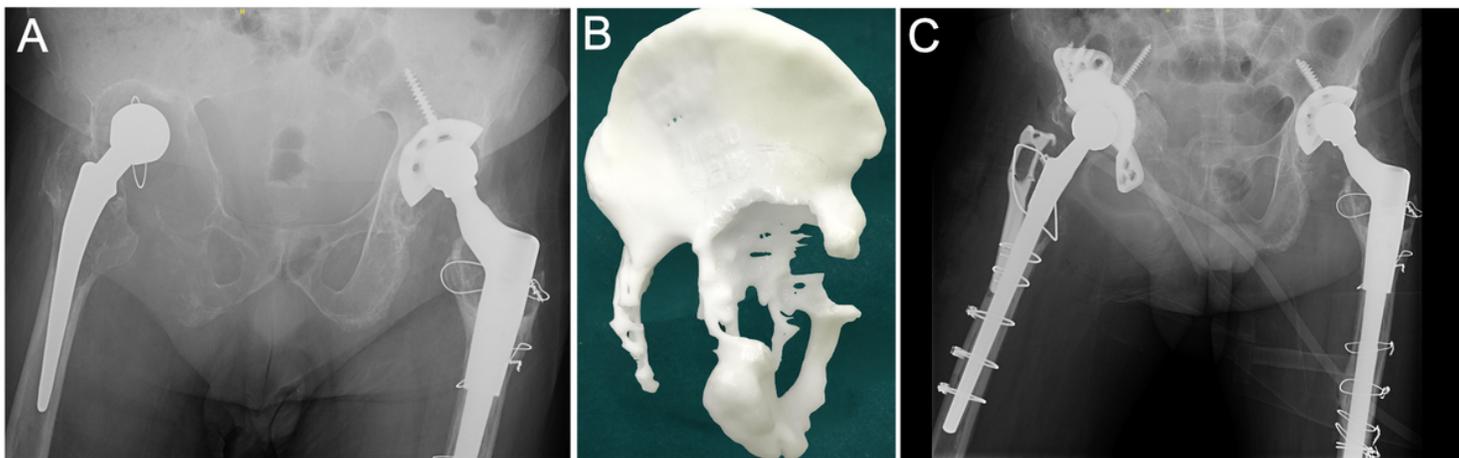
**Figure 7**

A. A 68-year-old male was diagnosed as aseptic loosening 20 years after THA. B. RP showed that the entire superior acetabulum was defected while the ischial ramus and the pubic ramus was intact. The remaining bone was difficult to support the rotational and vertical stability of the cup. An augment was designed to rebuild the superior acetabulum. The vertical stability could be achieved and the rotational stability could be ensured by clamping the cup with the superior augment, the ischial ramus and the pubic ramus. C. Acetabulum reconstruction was made by three customized augments reinforcing the superior acetabulum and a commercial cup.



**Figure 8**

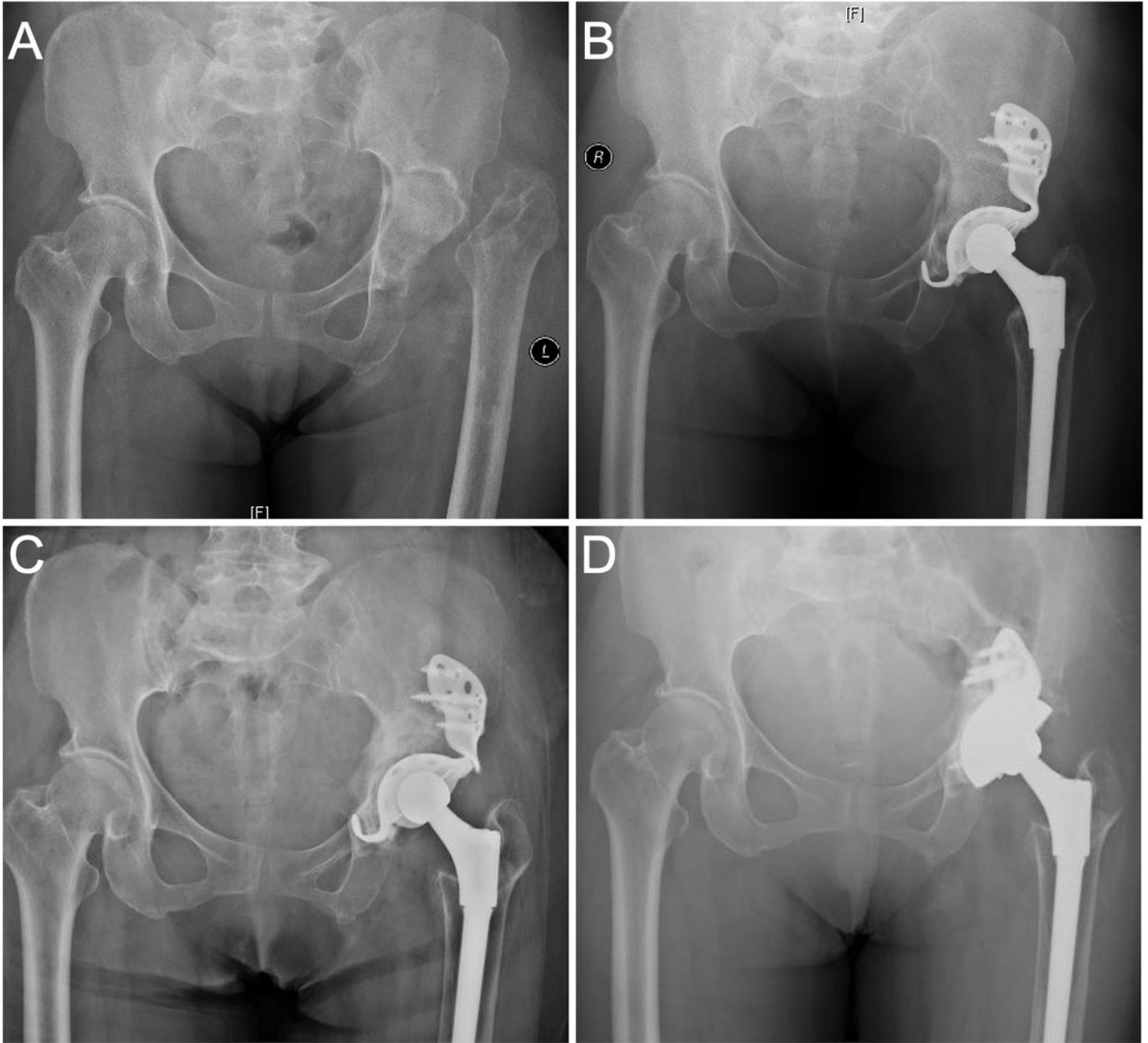
A. A 60-year-old female was diagnosed as aseptic loosening 1 year after right hip revision. B. RP showed the inferior, superior and anterior acetabulum and the ischial ramus was defected. The vertical and rotational stability of the cup cannot be obtained and it was difficult to reconstruct one place by augments to obtain a firmly clamped cup. C. A customized cage was used. Rotational stability was obtained with cage wing fixed into the ala of ilium and the ischial ramus by screws. Vertical stability was ensured by the acetabular cup directly contacting the superior host bone.



**Figure 9**

A. A 54-year-old male was diagnosed as right hip prosthesis loosening 24 years after THA. B. RP showed severe osteolysis around the acetabulum involving the superior and inferior acetabulum, the ischial ramus and the pubic ramus. Some ischial ramus cortical bone remained on RP, but it was proved to be radiopaque bone cement in operation and the ischial ramus was completely destroyed (We had reported this specific intraoperative finding and other misleading cases under RP in another study in detail<sup>22</sup>). The vertical and rotational stability could not be obtained. C. Although the operation was managed with a customized cage, we believed that the primary stability was insufficient because the cage was fixed to the

ala of ilium only by a screw in the superior. Such patients might benefit more from customed hemi-pelvic prosthesis.



**Figure 10**

A. A pelvis anteroposterior radiograph taken before the first operation. B. A radiograph was taken right after the first operation and a commercial cage was used. C. 7 years after the first operation, fatigue failure happened in the connection between the wing and cup. D. A high friction coefficient revision cup was used for revision.